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VSB-30 sounding rocket: history of flight performance

Abstract: *The VSB-30 vehicle is a two-stage, unguided, rail launched sounding rocket, consisting of two solid propellant motors, payload, with recovery and service system. By the end of 2010, ten vehicles had already been launched, three from Brazil (Alcântara) and seven from Sweden (Esrange). The objective of this paper is to give an overview of the main characteristics of the first ten flights of the VSB-30, with emphasis on performance and trajectory data. The circular 3σ dispersion area for payload impact point has around 50 km of radius. In most launchings of such vehicle, the impact of the payload fell within 2 sigma. This provides the possibility for further studies to decrease the area of dispersion from the impact point.*
Keywords: *VSB-30, Sounding rocket, Trajectory, Performance.*

INTRODUCTION

The VSB-30 vehicle is a two-stage, unguided, rail launched sounding rocket, consisting of a solid propellant S31 rocket booster, a boost adapter, the second stage S30, payload, a recovery and a service systems. Motor and payload are connected by an adapter section and they are separated by pneumatic pistons. The vehicle is designed to fly in a spin stabilized unguided mode. The spin stabilization is achieved by using canted fins. To reduce impact dispersion, the vehicle is equipped with three spin-up motors, installed in the booster adapter. The fins are arranged in the standard three-fin configuration and they are nominally set to 18’ (S31) and 21’ (S30), respectively, causing the vehicle to spin from lift-off through burnout. The roll rate at burnout is approximately 3.3 Hz. Total action time for the S31 is 16.0 seconds and 32.0 seconds for the S30. Both motors have a 22-inch diameter (557 mm) (Jung and Gomes, 2006).

In 1976, Germany’s national Texus sounding-rocket programme was started and it continues to the present day. Texus (*Technologische Experimente unter Schwerelosigkeit*) used British Skylark seven rockets, which provided about six minutes of microgravity. Only recently, in 2005, the Skylark ceased to be commercially available, so that from Texus 42 onwards (November 2005) the Skylark Seven has been replaced by the Brazilian VSB-30 rocket, (Seibert, 2006).

In 1996, the German Aerospace Center (DLR) proposed to *Comando Geral de Tecnologia Aeroespacial* (DCTA) the adaptation of its Mini-TEXUS payload to the first stage of SONDA III, which had its first flight in 1976. This new single stage vehicle was known as VS-30. In 2001, the Unified Microgravity Program for Sounding Rockets proposed to DCTA the development of a boosted version of the VS-30. The challenge was accepted, and the development of the S31 booster motor started. The qualification of the motor consisted of three static firings. The maiden flight was from the Alcântara Launcher Center (CLA) in 2004, (Palmério *et al*., 2003).

The first operational flight from Esrange was in 2005. TEXUS is the European/German sounding rocket programme, which serves the microgravity programmes of the German Aerospace Center (DLR) and of the European Space Agency (ESA). The launches are conducted from Esrange, in Sweden.

Figure 1 shows a sequence of pictures from the time of the launch of VSB-30 V07 in 2010 from the CLA.

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Figure 1. VSB-30 being launched from Alcantara Launcher Center.

OBJECTIVES

The objective of this paper is to give an overview of the main characteristics of the first ten flights of the VSB-30, with emphasis on performance and trajectory data. After briefly delving into the history of the VSB-30 sounding rocket in the Introduction, the idea is to give a brief overview of the architecture, the sequence off light events in a typical mission, the list of flown missions, and, finally, the trajectory and flight information for each mission. The final sections of this article deal with the uncertainty in the impact point of the vehicle and the factors affecting it.

ARCHITECTURE

The basic architecture of VSB-30 is presented in Fig. 2 (Jung, 2006).

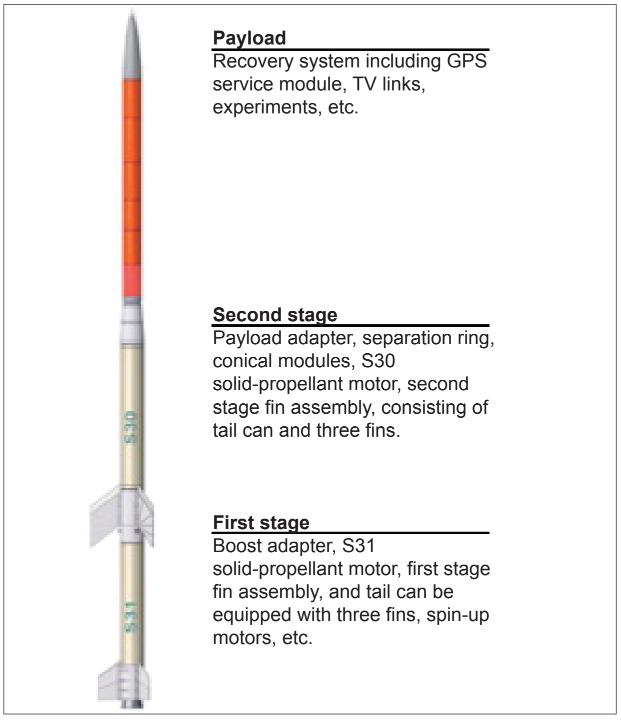

Figure 2. Basic architecture from VSB-30.

FLIGHT EVENTS

The VSB-30 flight events sequence is presented in Table 1 and Fig. 3 (Garcia, 2010).

Table 1. Main events of flight.

Events	Time (s)	Altitude (km)	Range (km)
First stage ignition	0.00	0.051	0.00
Lift-off	0.45	0.056	0.00
Burn-out of 1st stage / separation	13.5	3.617	0.450
Ignition of 2nd stage	15.0	4.323	0.552
Apogee of 1st stage	31.0	6.511	0.970
Burn-out of 2nd stage	44.0	43.1	7.32
Nose cone ejection	55.0	64.3	11.3
Yo-Yo release	56.0	66.1	11.6
Second stage /payload separation	59.0	71.7	12.7
Impact of 1st stage	106.0	0.00	1.1
Payload apogee	259.0	252.7	81.1
Flight time above 100 km		368 s	
Drogue chute deployment	492.6	6.1	154.7
Payload impact (without parachute)	497.0	0.00	155.6

LIST OF CAMPAIGNS

Table 2 provides the selected information about the first 10 VSB-30 campaigns.

IMPACT POINT DISPLACEMENT

The impact point showed in Fig. 4 for each flight of the VSB-30 is a statistical displacement of the actual impact point from the predicted one. It is used to calculate the probability of impact within a given distance from the nominal impact point. The distance is referenced to a sigma value. For VSB-30 the radius of 3 sigma is around 50 km. The following procedure was used to determine the actual impact displacement or miss-distance for each flight (Bristol Aerospace, 1968).

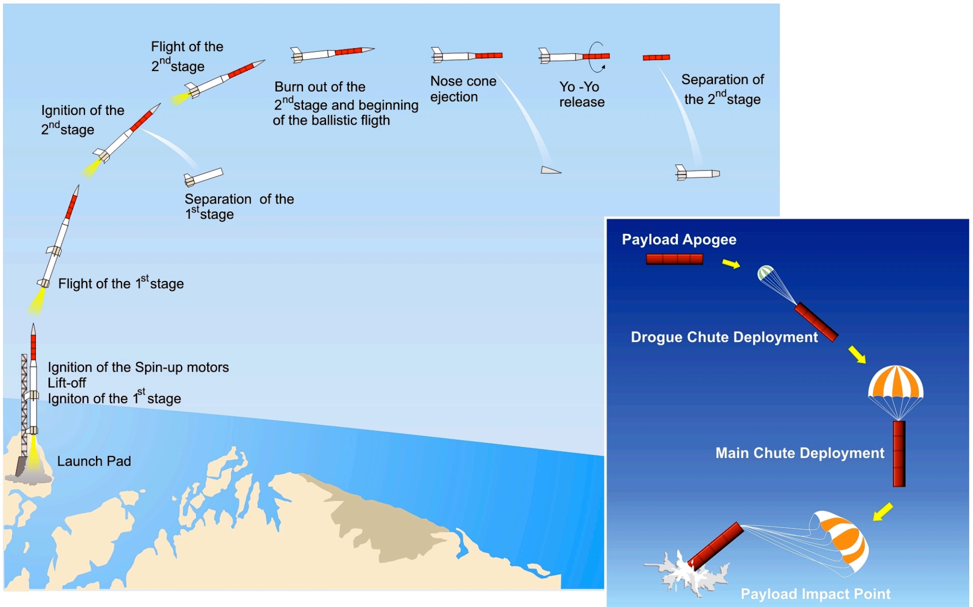

Figure 3. VSB-30 flight events.

Table 2. List of VSB-30 campaign.

Logo mark	Flight number / payload name and mass	Launch day	Country/ Launch center	Logo mark	Flight number / payload name and mass	Launch day	Country/ Launch center
	VSB-30 V01 Cajuana (392.0 kg)	October 23, 2004	Brazil, Alcântara		VSB-30 V05 Texus 44 372.0 (kg)	February 07, 2008	Sweden, Esrange
					VSB-30 V06 Texus 45 (367.0 kg)	February 21, 2008	Sweden, Esrange
	VSB-30 V02 Texus 42 (372.2 kg)	December 01, 2005	Sweden, Esrange		VSB-30 V07 Maracati II (391.25 kg)	December 12, 2010	Brazil, Alcântara
	VSB-30 V03 Texus 43 (407.4 kg)	May 11, 2006	Sweden, Esrange		VSB-30 V08 Maser 11 (383.0 kg)	May 15, 2008	Sweden, Esrange
	VSB-30 V04 Cumã II (350.9 kg)	July 19, 2007	Brazil, Alcântara		VSB-30 V09 Texus 46 (393.7 kg)	November 22, 2009	Sweden, Esrange
					VSB-30 V010 Texus 47 (362.1 kg)	November 29, 2009	Sweden, Esrange

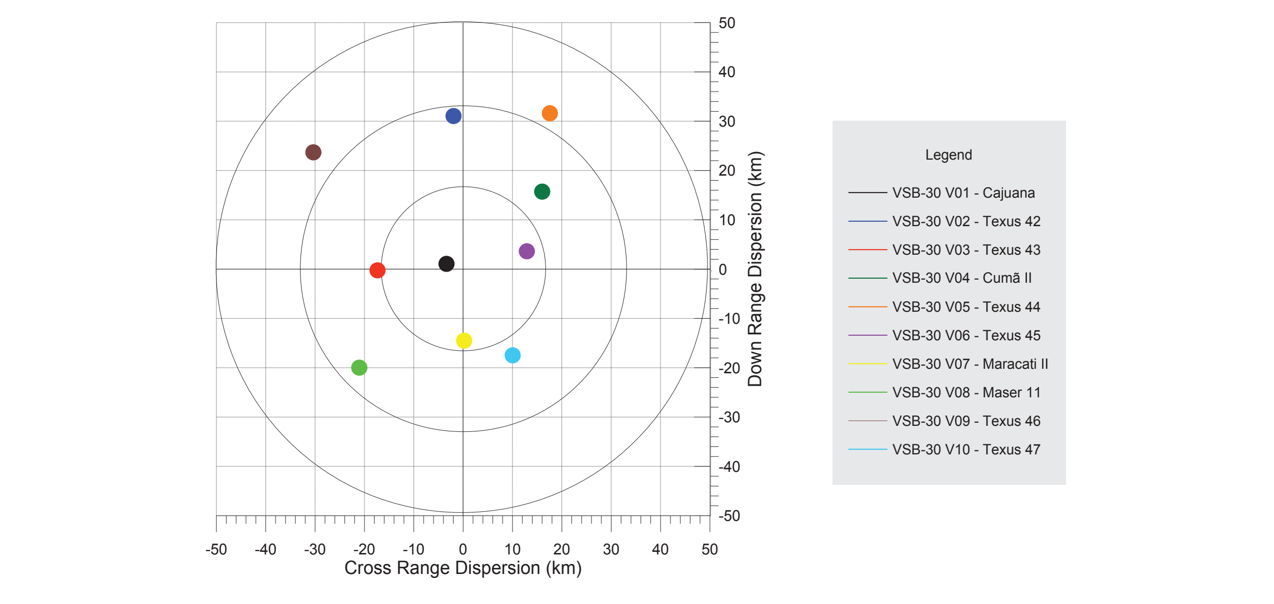

Figure 4. VSB-30 actual dispersion operational flights.

Step 1	Impact displacement in-range (ΔInR)	$\Delta InR = -I_p + I_a \cos(\alpha_p - \alpha_a)$
Step 2	Impact displacement in cross range (ΔCr)	$\Delta Cr = -I_a \,\mathrm{sen}(\alpha_p - \alpha_a)$
Step 3	Total impact displacement (ΔTotal)	$\Delta Total = \sqrt{\Delta InR^2 + \Delta Cr^2}$

where:
I_p: predicted impact range;
I_a: actual impact range;
α_p: predicted impact azimuth;
α_a: actual impact azimuth.

FLIGHT PERFORMANCE

Figure 5 gives the actual vehicle altitude *versus* the range for each of the first ten VSB-30 campaigns.

Table 3 gives a comparison between nominal and actual data for Apogee and Ground Range. It also gives the flight time above 100 km and launcher settings values, for all campaigns. The setting and performance differences between each flight are associated with the rocket characteristic and the campaign objective.

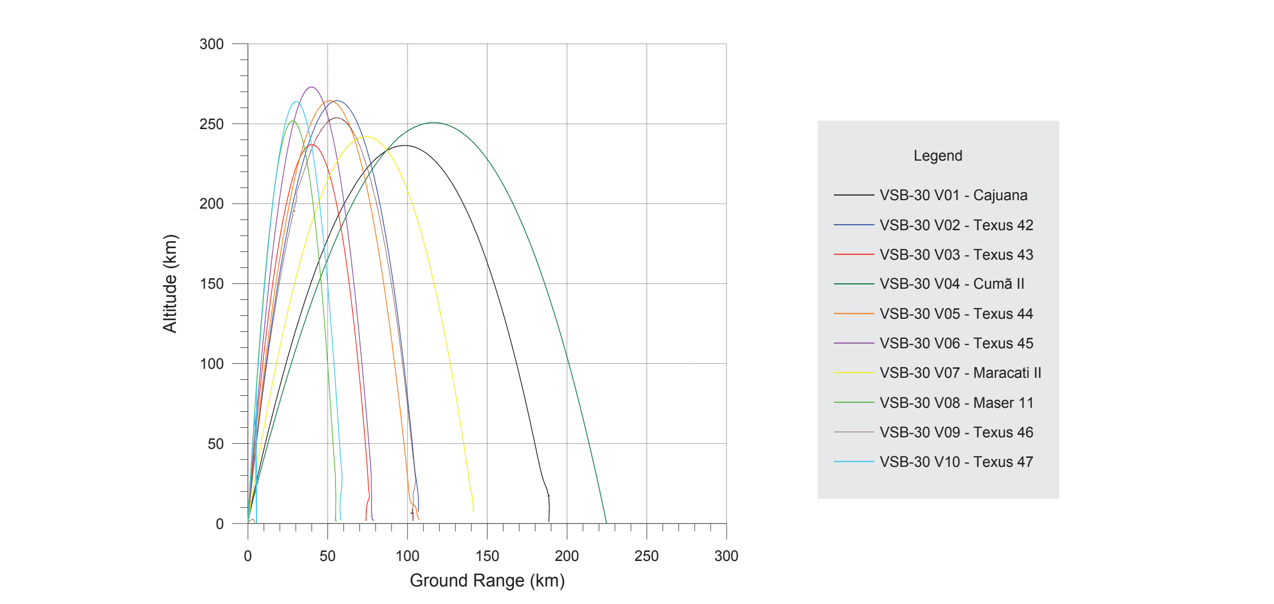

Figure 5. VSB-30 flight performance.

Table 3. Flight numerical information.

Flight number	Apogee (km) Nominal	Apogee (km) Actual	Ground range (km) Nominal	Ground range (km) Actual	Launcher setting Elevation (degree)	Launcher setting Azimuth (degree)	Flight time above 100 km (s)
01	254.0	236.0	188.0	189.0	84.0	45.0	347
02	257.0	264.4	75.0	106.0	87.7	350.0	380
03	248.5	237.0	72.3	74.0	87.7	350.0	346
04	272.0	250.0	208.5	224.7	83.5	65.0	365
05	270.0	264.4	74.0	107.0	87.9	350.0	380
06	270.0	273.0	74.0	78.6	87.9	350.0	390
07	252.7	242.0	155.6	141.0	85.0	60.0	354
08	258.0	251.8	72.0	56.0	87.9	352.5	365
09	256.1	253.3	75.9	104.0	87.8	352.3	366
10	264.0	264.2	75.0	58.3	87.8	352.3	380

DISPERSION AREA

The rocket motions during flight are governed by a number of forces and factors: motor thrust, aerodynamic forces, gravity, wind, wind shear, atmospheric friction, decrease of the rocket mass resulting from the consumption of propellants during flight, the movement of the center of gravity during that process, and forces generated by air rudders and jet vanes (Ordway *et al*., 2007). The main contributors to the dispersion of impact parts of this type of rockets are manufacturing or assembly misalignments and the wind (James, 1961). Wind dispersion could be made less significant by the use of wind-compensation techniques and automations procedures to set the position of the launcher. In Brazil, the calculation of the adjustment of the azimuth and elevation angles is made for a dedicated software called “Guará” (Yamanaka and Gomes, 2001). This software needs the real-time information about direction and velocity of the wind.

The dispersion area is calculated by using rocket parameter error of mass, thrust, aerodynamic, winds, drag of parachute, launcher setting, and so on. The circular 3Σ dispersion area for the VSB-30 payload has around a radius of 50 km, using the parameters error listed in Table 4. For that analysis, all perturbation factors are considered. Statistically it implied that the dispersion factors will, in more than 99% of all cases, be less than or equal to the values assumed. Impact displacements, caused by the individual factors, are then combined by the square root of the sum of the squares (of the displacements) to give a 3Σ tolerance, (Scheuerpflug, 2009). We can see in Fig. 5 that all impact points for the ten VSB-30 are into the dispersion area. The mathematical method used to calculate the dispersion is the residual sum of square (RSS) by a software called TDA (Garcia and Louis, 2005).

Table 4. Error parameters used for VSB-30.

Flight events	
First stage (S31 burning)	
Parameters	**Error**
Thrust variation	3%
Thrust misalignment in pitch	0.1º
Thrust misalignment in yaw	0.1º
Aerodynamic drag	20%
Weight variation	1%
Fin misalignment	0.01º
Launcher elevation error	0.5º
Launcher azimuth error	3.0º
Head wind	2 m/s
Cross wind	2 m/s
Second stage (S30 burning)	
Parameters	**Error**
Thrust variation	3%
Thrust misalignment in pitch	0.1º
Thrust misalignment in yaw	0.1º
Aerodynamic drag	20%
Weight variation	1%
Ignition time variation	2 s

The circular 3Σ dispersion area from payload impact point for the VSB-30 has around a radius of 50 km. In most launchings of this vehicle, the impact of the payload fell within 2 sigma. This provides the possibility for further studies to decrease the area of dispersion from the impact point.

There are other options to decrease the dispersion area, one of that is an automatic system to set the launcher position in real time, the nearest possible moment of the launching, after any wind perturbation on launcher in the time of the rocket countdown, considering all the terms of the flight security in an unguided sounding rocket campaign (Garcia, 2007).

COMMENTS AND CONCLUSIONS

Contributions concerning the possibility of decreasing the impact point dispersion area could minimize many operational problems, such as coats, payload rescue, maritime interdiction area, etc.

Other specific objectives of the VSB-30 are: to support the Project of AEB Microgravity allowing organizations, to teach, to research and to develop by performing scientific experiments and technology through suborbital flights; to enhance the partnership with the German Aerospace Center (DLR) in the space-related suborbital launch vehicle and to perform experiments in microgravity.

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